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(71) Applicant (*for all designated States except US*): **RESLINK AS** [NO/NO]; Kongsgata, Postboks 204, N-4339 ÅLGÅRD (NO).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **DYBEVIK, Arthur** [NO/NO]; Harriet Backersgt. 29, N-4307 SANDNES (NO). **CHRISTENSEN, Ove, Sigurd** [NO/NO]; Rollaugsgata 28, N-4141 HAFRSFJORD (NO). **MOEN, Terje** [NO/NO]; Diamantveien 36 A, N-4318 SANDNES (NO).

(74) Agent: **HÅMSØ PATENTBYRÅ ANS**; P.O. Box 171, N-4302 SANDNES (NO).

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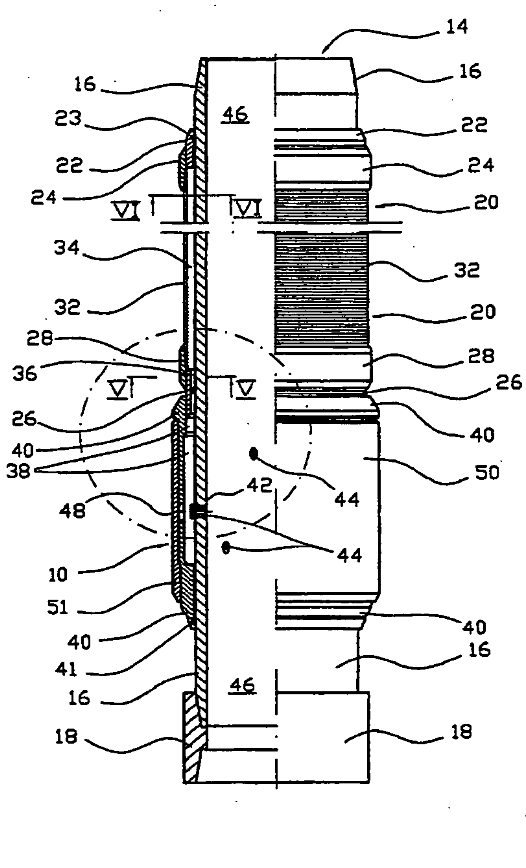
# (54) Title: A WELL DEVICE FOR THROTTLE REGULATION OF INFLOWING FLUIDS




**(57) Abstract:** A flow arrangement (10, 12) for use in a well through one or more underground reservoirs, and where the arrangement (10, 12) is designed to throttle radially inflowing reservoir fluids produced through an inflow portion of the production tubing in the well, the production tubing in and along this inflow portion being provided with one or more arrangements (10, 12). Such an arrangement (10, 12) is designed to effect a relatively stable and predictable fluid pressure drop at any stable fluid flow rate in the course of the production period of the well, and where said fluid pressure drop will exhibit the smallest possible degree of susceptibility to influence by differences in the viscosity and/or any changes in the viscosity of the inflowing reservoir fluids during the production period. Such a fluid pressure drop is obtained by the arrangement (10, 12) comprising among other things one or more short, removable and replaceable flow restrictions such as nozzle inserts (44, 62), and where the i

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A WELL DEVICE FOR THROTTLE REGULATION OF INFLOWING FLUIDS

The present invention regards a flow device for throttling and thereby causing a pressure drop in fluids that through the device flow radially into the drain line of a well, preferably a petroleum well, in connection with said fluids being produced from permeable rocks in one or more underground reservoirs. In the petroleum industry, said drain line is ordinarily termed production tubing, and said drain line will hereinafter simply be termed production tubing, even when this drain line is not used in a petroleum well.

In connection with the production of such fluids, e.g. hydrocarbons, said device is preferably used in a horizontal or approximately horizontal well, and where such a well is hereinafter simply termed a horizontal well. The device is particularly advantageous when used in a well with a long horizontal reach in the underground reservoir(s) in question. On the other hand, the invention is not limited to exclusive use in horizontal wells, as the invention may equally well be

used in non-horizontal wells such as vertical wells and deviated wells.

The invention has been developed as a result of the need to prevent or reduce a number of production engineering problems associated with the production of hydrocarbons via horizontal wells.

On the upstream side of a horizontal well, its production tubing is provided in the horizontal or near-horizontal section of the well, hereinafter simply termed a horizontal section of the well. During the production of hydrocarbons, the reservoir fluids flow radially in through orifices or perforations in the production tubing. Depending on the nature of the reservoir in question, the production tubing may either be arranged in an open wellbore through the reservoir(s) in question, or it may be arranged in an enclosed production liner cemented into said open wellbore. The production tubing may as an option also have filters or so-called sand screens (also called slotted liners) that prevent formation particles from flowing into the production tubing along with the formation fluids.

When the reservoir fluids flow downstream and onwards in the horizontal section of the production tubing, said fluids are subjected to flow friction in the form of a frictional pressure drop. In the downstream direction, this frictional pressure drop normally exhibits a non-linear and strongly increasing pressure drop gradient, and where this pressure drop gradient occurs largely as a result of the continual draining of new volumes of reservoir fluid into and along the production tubing downstream of said horizontal section. Thus

the flow rate of the fluids increases in the downstream direction. As a result of said pressure drop gradient, the internal fluid flow in the production tubing will therefore exhibit a non-linear and greatly decreasing fluid pressure gradient in the downstream direction. At production start-up however, the fluid pressure in the surrounding reservoir rock will often be relatively homogenous and change very little along the horizontal section. At the same time, the frictional pressure drop of the fluids when flowing from the reservoir rock and radially into the production tubing is small in comparison with the frictional pressure drop of the fluids in and along the horizontal section of the well. At any position along this horizontal section, the pressure difference (differential pressure) that arises between the fluid pressure in the reservoir rock and the corresponding fluid pressure inside the production tubing will therefore exhibit a non-linear and strongly increasing differential pressure gradient. This is the real reason for the production engineering problems that this invention, for one, seeks to solve or limit. In practice, such a differential pressure gradient allows the radial inflow rate of the fluids pr. unit length of the horizontal section to be significantly greater at the downstream side (the "heal" of the well) than at the upstream side (the "toe" of the well) of the horizontal section.

When producing hydrocarbons via a horizontal well, experience often goes to show that the radial inflow rate pr. unit length of the horizontal section is significantly greater in some reservoir zones than in other zones of the same reservoir, and that said former zones are drained significantly faster than the latter zones. For most

horizontal wells, this means that most of the hydrocarbon production is produced from the reservoir zones at the downstream side of the horizontal section, i.e. at the "heal" of the well, while relatively small volumes of hydrocarbons are produced from zones along the remaining part of the horizontal section, and in particular from the upstream side of the horizontal section, i.e. the "toe" of the well. This leads to the quicker draining zones of the reservoir being drained of hydrocarbons earlier than other zones of the reservoir, and means that the fluid flow produced from the former zones may, at an earlier point than is desired, contain large unwanted amounts of water and/or gas. This variable production rate from the various zones of the reservoir also cause differences in fluid pressure between the reservoir zones, which may also lead to the formation fluids flowing among other things into and along an annulus between the outside of the production tubing and the borehole wall of the well, instead of flowing inside said production tubing. This is termed cross-flowing of reservoir fluids.

Said horizontal section may in some wells be several thousand meters long. The frictional pressure drop of the fluids in and along the horizontal section is considerable, and increases as a function of increasing well length. When using horizontal wells to produce hydrocarbons from reservoirs with a large horizontal dimension, a small thickness and high permeability, one may also experience so-called coning of water and/or gas from the reservoir in question and into and along the production tubing, which further amplifies said production engineering problems. Moreover, all naturally occurring reservoirs are heterogeneous, i.e. any naturally occurring reservoir will have three dimensional variations in

the nature of the reservoir, and where this appears in the form of variations in the physical and/or chemical characteristics of the reservoir. As an example, the spatial dimension of a reservoir rock may exhibit variations in porosity and permeability, and also variations in reservoir pressure and fluid composition. In addition, such natural variations increase further during the production of the reservoir fluids.

In order to avoid or reduce the variable production rate from the various zones of the reservoir, thus among other things avoiding or reducing differences in fluid pressure between the reservoir zones, it would be desirable for the reservoir fluids to flow into the production tubing at the same or approximately the same radial inflow rate pr. unit length of the horizontal section of the well. In order to achieve such identical or approximately identical inflow rate, the throttling of said radial inflow rate must be adjusted, and thus controlled, according to the prevailing conditions at the inflow position or zone in question in the reservoir. Such prevailing conditions first of all comprise the production rate of the well, and also the fluid pressure and the fluid composition both in the production tubing and in the reservoir rock; but other conditions such as the relative positioning of an inflow position with respect to the other inflow positions along the production tubing, and also the strength, porosity and permeability of the rock, must also be incorporated into the evaluation of the required throttling of inflowing reservoir fluids. Otherwise, these are circumstances and evaluations that are well known to those skilled in the art.

Devices that may be used when producing hydrocarbons via long horizontal and vertical wells are known among other things from patent publications GB 2 169 018; US 4 577 691; US 4 821 801 and US 4 858 691. Each such device comprises perforated production tubing, where the perforated tubing may be equipped with e.g. a filter or a sand screen to prevent formation particles from flowing into the well with the formation fluids.

The radial inflow rate of the fluids may be controlled to a certain degree by selecting an appropriate, often varying perforation density along said production tubing through the reservoir. Such a method of throttling is best suited in well completions, where a production liner is first cemented in place through the reservoir, and the tubing is then perforated to the appropriate degree and extent.

Also known is the use of arrangements consisting of one or more flow restricting devices (flow restrictions) for appropriate throttling of the radial inflow of formation fluids into such production tubing. The arrangements may also have downhole adjustable throttling of the fluids. As an example, the publications EP 0 588 421 (corresponds to US 5 435 393) and EP 0 858 548 (corresponds to US 6 112 815) explain how such devices may be allocated to production tubing running through a reservoir. On the basis of an assumed flow pressure drop gradient in and along the production tubing, and of the reservoir production profile and an assumed flow of inflowing formation fluids, it is possible through use of said arrangements of restrictions to control the inflow of hydrocarbons from the reservoir into the production tubing in an expedient manner.

In EP 0 588 421, the production tubing is made up of several stands (pipe sections), each of which is equipped with flow restrictions in the form of one or more inflow channels. The inflow channel(s) is/are arranged in an opening or an annulus between the outside of the production tubing and the inside of e.g. a bulb or a sleeve of the production tubing. In one embodiment, and for each stand, the inflowing formation fluids are first passed through a so-called sand filter and then downstream, onwards through said inflow channels, in order to then flow into the production tubing in the well. The publication shows that such inflow channels may be made up of one or more longitudinal thin pipes, bore or grooves, through which the fluids flow while being experiencing a fluid pressure drop as a result of the flow friction in said channels. For each of said stands, the pressure drop through the associated flow restriction(s), and thereby also the fluid pressure in each stand, may to a large degree be controlled by providing each stand with an appropriate number of pipes, bores or grooves, and where the pipe(s), bore(s) or groove(s) in question is/are also given an appropriate geometrical shape, e.g. a suitable cross section of flow and/or length of the pipe, bore or groove.

EP 0 858 548 also deals with such production tubing having stands (pipe sections) equipped with one or more flow restrictions arranged in an opening or an annulus between the outside and inside of the production tubing. An axially movable sleeve, the external surface of which is formed with axially extending, helical grooves, is arranged in said opening or annulus in a manner such that the helical grooves abut a surrounding but stationary tubular sleeve and form inflow channels through which the formation fluids may flow

and be throttled. Said movable sleeve may by means of male threaded connections and an actuator device such as a remote control hydraulic, electric or pneumatic actuator/motor, be displaced in the axial direction, covering the outlet orifice of the restriction, i.e. the opening into the inside passage of the production tubing, to the desired degree, to allow the inflowing fluids to be throttled as desired or completely shut off the fluid inflow. The fluids flowing through the helical grooves will, like the inflow channels described in EP 0 588 421, also experience flow friction and an associated fluid pressure drop. On the other hand, the geometrical shape of the helical grooves causes a much greater degree of turbulence in the fluid flow, and through this a much larger fluid pressure drop in the fluid flow, than in the case of the type of flow restrictions described in EP 0 588 421. Thus, according to EP 0 858 548, the axially movable sleeve equipped with external helical grooves represents a simpler and more reliable device for throttling inflowing formation fluids, and also for controlling flow by means of remotely controlled means, than the throttling devices described in EP 0 588 421. Such remotely controlled means may include remotely controlled valves, displaceable flaps, plates or pistons, actuators and motors.

In well completions, where the production tubing or a surrounding production liner is cemented into the reservoir, and where one wishes to control the throttling of the radial inflow of reservoir fluids by selecting an appropriate perforation density along those reservoir zones that are to be drained, the production tubing/production liner may be perforated by means of explosive charges that are lowered on and activated via a cable or coiled tubing disposed in the

well. The charges are arranged so as to achieve the desired perforation density in said zones, and where the perforation density may vary from zone to zone, and possibly also within one zone. Such perforation of cemented pipes will however cause much greater damage to the immediately surrounding reservoir zones than when using non-cemented pipes. This greater formation damage effect, which in technical terminology is termed and expressed through a so-called "skin factor", normally causes the reservoir fluids to experience a larger fluid pressure drop when flowing radially in towards the cemented pipe of the well, and results in the fluids containing more loose formation particles than in the case of fluid flow in towards non-cemented pipes. Moreover, it may be difficult to control and predict the degree of formation damage effect associated with the use of explosives for perforating pipes and cement, which is partly related to the fact that the reservoir zones are heterogeneous and may exhibit different formation properties within a reservoir. This means that the formation damage effects, and thereby also said fluid pressure drop and inflow of formation particles, may be distributed unevenly along the perforated intervals of the well. Such artificially introduced increases and/or unequal distribution of fluid pressure drops make it more difficult to plan and control the throttling of the radial inflow rate of the reservoir fluids along the well.

In addition, there will always be a certain safety risk associated with the transport, use and storage of such explosive charges. Among these is a certain uncertainty associated with the question of whether all the charges, or how many charges, detonate in the well, and/or whether the charges detonate in the correct place in the well, and/or

whether the resulting perforations show sufficient quality as inflow openings. In some cases, the charges may be detonated inadvertently, e.g. when running the charge into the well, thereby inadvertently perforating zones of the well that were not to be perforated, e.g. zones outwith the reservoir zones. Even in the case of a successful perforation of the production tubing/liner in the well, it may still not be possible through the detonation to control the geometrical shape and cross section of flow of the individual perforations, which among other things is required in order to allow more accurate control of the fluid flow rate and pressure drop through the perforations.

In well completions where one or more remotely controlled means such as remotely controlled valves, displaceable flaps, plates or pistons, actuators and motor is/are used to control and adjust the fluid inflow from one or more reservoir zones in a well, fine mechanical and/or electronic components are often used in or in association with such means. Such technical solutions are often both expensive and complex, in addition to being burdened with several limitations on use, e.g. in connection with the functionality of said components under the prevailing conditions in a well, such as temperature and pressure. In practice therefore, such remotely controlled means often end up failing or functioning unsatisfactorily, even after a short period of being used in a production well.

In addition, the flow restrictions in themselves may be complicated to produce and/or assemble in a pipe. As an example, the flow restrictions described in EP 0 588 421 require the use of extensive and costly tools in order to

assemble the restriction(s) and thereby produce the restriction means. In addition, the flow restrictions described in EP 0 858 548 are meant to represent devices that, when compared with the means described in EP 0 588 421, are easier to manufacture and give more reliable throttling of inflowing formation fluids.

For all of the above and known throttling arrangements/devices and or methods of throttling, it may still be difficult when producing the reservoir fluid to achieve the fluid pressure drop desired at any time through the individual flow restriction or flow arrangement in the well. This is due largely to the fact that the physical and chemical conditions of the reservoir change in the course of the production period, with the changes all the time affecting the inflowing reservoir fluids, among other things in the form of changes in said fluid pressure drop. As an example, the fluid pressure and fluid composition of the reservoir fluids will change gradually through said period. Therefore, the produced fluids may contain both liquid and gaseous phases, including different liquids and/or gases, and where the mutual quantitative proportions of the different fluids also change with time. Among other thing, this is connected with the fact that there is normally a certain segregation of the fluids in the reservoir, where the segregation occurs as a result of the different specific gravities of the different reservoir fluids. This gives rise to the classical division of the fluids in a reservoir into different fluid layers, e.g. into a top layer of gas (a so-called gas cap), an intermediate layer of oil, and a lower underlayer of water (formation water). Incidentally, many reservoirs have no gas cap, and are initially made up only of

an oil layer and an underlayer of water. On the other hand, but to a varying extent, the reservoir fluids in all hydrocarbon reservoirs are segregated further, especially the oil phase of a reservoir, based on differences in the specific gravity of the fluids. When producing fluids from such a reservoir, one seeks, in principle, only to extract the hydrocarbons of the reservoir. At the same time, the volume of hydrocarbons that is removed from the reservoir during production must be replaced by other fluids that are naturally or artificially (e.g. via water flooding) introduced to the reservoir. Over time, such production related displacement of reservoir fluids will cause the borderlines between said fluid layers to be displaced gradually in the reservoir. This normally causes a change in the fluids or fluid compositions flowing into the well, and also a change in the viscosity of the fluids. If, in addition, there is a large degree of capillary action in the pores of the reservoir rock, the fluid layer borderlines, and especially the borderline between oil and water (the oil-water contact), will be made up of an interface in the reservoir. Such an interface will, like a fluid layer borderline, also move in the reservoir during the course of the production period. In the interface is a mixture of fluids, e.g. a mixture of oil and water, from either side of the interface, where the mutual quantitative proportions of the fluids (fluid saturation), e.g. the oil/water ratio, will change gradually from one side of the interface to the other side of the interface.

As hydrocarbons are produced from e.g. an oil reservoir, the fluid pressure in the reservoir will be gradually reduced as a natural consequence of the removal of fluids from the

reservoir. Thus some hydrocarbon gases will, in connection with the gradual reduction in pressure, not be able to remain dissolved in the oil phase of the reservoir, and an increasing amount of such gases will then be released from the oil phase and be mixed in with the fluids flowing into a well. Uneven fluid pressure distribution in a reservoir caused by variable production rates from the different zones of the reservoir leads to such gases first being released from the reservoir zones(s) having the lowest fluid pressure, and where gas from said zone(s) will flow into this/these area(s) of the well. This gives an irregular production profile from the reservoir, and is disadvantageous in terms of production engineering.

All such gradual physical and/or chemical changes in the composition and properties of the reservoir fluids that in the course of a production period flow radially into a well, affect the fluid pressure drop that occurs through the flow restrictions/arrangements of the well. It is general knowledge that both the specific gravity and the viscosity of a fluid have an effect on the fluid pressure drop that occurs when the fluid flows through such a restriction. It is also generally known, especially in connection with the production of hydrocarbons from a reservoir, that the viscosity of the reservoir fluids may vary within a wide range of viscosity values during the course of the production period. The specific gravity of the fluids on the other hand, and especially the specific gravity of the reservoir liquids, will, for the same period and the same reservoir fluids, normally vary within a relatively narrow range of specific gravity values.

As an example, the formation water in an oil reservoir may have a viscosity of 1 centipoise (cP) and the crude oil may have a viscosity of 10 cP, while a mixture of 50 vol% formation water and 50 vol% crude oil may have a significantly higher viscosity, e.g. 50 cP or more. Such a mixture of water and oil often has a significantly higher viscosity than that of the individual liquid components that enter into the mixture. The increased viscosity of the oil/water mixture is a result of the formation of viscous oil/water emulsions during the mixing of oil and water, and where the degree of emulsification depends, among other things, on the mixture ratio of the two immiscible liquid components. In this connection, it is also general knowledge that turbulent flow conditions are particularly favourable for the formation of oil/water emulsions.

For comparison with the above viscosity values, the same formation water may have a specific gravity of 1.03 ($kg/dm^3$), and the same crude oil may have a specific gravity in the order of 0.75-1.00 ($kg/dm^3$). Hence it follows that a mixture of formation water and crude oil will have a specific gravity in the order of 0.75-1.03 ($kg/dm^3$), depending on the mixture ratio of the liquid components.

This comparison between the viscosity values and specific gravity values of certain reservoir liquids shows that it is necessary during a production period, and for production purposes, to relate to a very wide range of viscosity values for the inflowing liquids, and where the viscosity values may also change significantly, possibly gradually and/or frequently, over time. On the other hand, and at the same

time, it is only necessary to relate to a relatively narrow range of specific gravity values for the inflowing liquids.

Consequently, a flow restriction designed so as to cause a fluid pressure drop through the restriction which to a large degree is influenced by the viscosity or any changes in viscosity of the inflowing formation fluids, will also exhibit pressure drops or changes in pressure drop that are in accordance with said viscosity or changes in viscosity. As opposed to this, a flow restriction that is designed so as to cause a pressure drop through the restriction which to a large degree is influenced by the specific gravity or changes in specific gravity of the inflowing formation fluids, will exhibit small pressure drops or changes in pressure drop through the restriction in question through the production period, especially if the inflowing fluids consist only of liquids, e.g. oil and water.

The flow restrictions/arrangements described in EP 0 588 421 and EP 0 858 548 are both based on throttling of inflowing fluids through one or more inflow channels, and where the inflow channels are formed as longitudinal pipes, bores or grooves with a small cross section of flow. Upon fluid flow through such channels, which will be described in the following, the fluid pressure drop through such restrictions is influenced largely by among other things the viscosity of the fluid, and where said fluid pressure drop will change in accordance with any changes in viscosity in the inflowing fluids. If the produced fluids are expected to show significant, and possibly gradual and/or frequent changes in viscosity over time, the latter flow restrictions/arrangements can not be expected to effect a

relatively stable fluid pressure drop through the production period. The flow restrictions/arrangements described in EP 0 858 548 are furthermore specially designed to cause a fluid pressure drop by means of turbulent flow through the restriction/arrangement, and where the pressure drop that results from the turbulent flow will be greater than the pressure drop that would occur in the case of laminar flow through the same restriction/arrangement.

As mentioned, and in the case of fluid flow through inflow channels, the fluid pressure drop '$\Delta p$' through such restrictions is influenced largely by among other things the viscosity of the fluid.

In the case of laminar flow of a fluid through a pipe having a circular cross section, '$\Delta p_{lam}$' may be generally expressed by:

$\Delta p_{lam} = R_{lam} \cdot Q$ ; where

'$R_{lam}$' is a factor expressing the laminar flow resistance of the fluid in the pipe, and where '$R_{lam}$' is proportional to the viscosity of the fluid and otherwise a function of the geometrical shape of the pipe (length, pipe cross section/diameter); and

'$Q$' is the fluid flow rate through the pipe.

In the case of the more complex and turbulent flow of a fluid through a pipe having a circular cross section, '$\Delta p_{turb}$' may be generally expressed by:

$$\Delta p_{turb} = R_{turb} \cdot Q^2 \qquad ; \text{ where}$$

'$R_{turb}$' is a factor expressing the turbulent flow resistance of the fluid in the pipe, and where '$R_{turb}$' is proportional to the viscosity, specific gravity and flow velocity of the fluid, and also a function of the geometrical shape and internal surface roughness of the pipe; and

'Q' is the fluid flow rate through the pipe.

This shows that the fluid pressure drop that occurs during fluid flow through such inflow channels is influenced by many factors, including viscosity, and as such it may be difficult to design a flow restriction which is based on this type of fluid flow, in a manner so as to effect a conditionally adapted, relatively stable and predictable fluid pressure drop through the restriction.

The primary object of the invention is to provide a flow arrangement for use in a well of the type that penetrates one or more underground reservoirs, and where the arrangement is designed to throttle the pressure of reservoir fluids that, in an inflow portion of the production tubing in the well, flow in radially from said reservoir(s) through at least one such flow arrangement and into the production tubing, and where said arrangement is designed to effect a relatively stable and predictable fluid pressure drop at any stable fluid flow rate in the course of the production period of the well, this fluid pressure drop being adjusted according to the prevailing pressure conditions at the relevant position of the arrangement along the inflow portion of the production tubing, and also to the radial inflow rate of the reservoir

fluids in this portion, and where said fluid pressure drop exhibits the smallest possible degree of susceptibility to influence by differences in the viscosity and/or any changes in the viscosity of the inflowing reservoir fluids during the production period. Thus each flow arrangement along said inflow portion may be designed to effect a certain fluid pressure drop adjusted according to the relevant fluid pressure in the production tubing at the individual flow arrangement, and where said fluid pressure drop for each flow arrangement gives the appropriate reduction of the differential pressure driving the reservoir fluids from the outside of the production tubing, through the flow arrangement in question, and into the production tubing.

By thereby designing each flow arrangement to effect an appropriate fluid pressure drop, it is possible to achieve the overall object of the invention, which is to ensure that reservoir fluids from the various reservoir zones flow into the well at the same or approximately the same radial inflow rate pr. unit of length of the inflow portion of the production tubing. By so doing, the above disadvantages of prior art are reduced or avoided.

The object is achieved by, in the inflow portion of the production tubing, passing all or partial flows of the inflowing reservoir fluids up to and throttling them through one or more flow arrangements designed so as to effect an associated fluid pressure drop through the arrangement(s), which pressure drop is mainly influenced by the specific gravity and flow rate/flow velocity of the fluids. Such a fluid pressure drop may be achieved if the produced fluids are led up to and throttled through at least one short

restriction, e.g. an orifice in the form of a slit or a hole, or a nozzle.

The fluid pressure drop '$\Delta p$' through such a short restriction is constituted by the energy loss or pressure difference that occurs in the dynamic pressure of a fluid when this fluid flows through the restriction, and where, according to Bernoulli's equation, the dynamic pressure 'p' of the fluid may be expressed by:

$p = \frac{1}{2} (\rho \cdot v)$ ; where

'$\rho$' is the specific gravity of the fluid; and

'$v$' is the flow velocity of the fluid.

Thus the fluid pressure drop '$\Delta p_{1-2}$' between an upstream position 1 and a downstream position 2 in the short restriction may be expressed in the following way:

$\Delta p_{1-2} = \frac{1}{2} \rho \cdot (v_1^2 - v_2^2)$ ; where
'$\rho$' is the specific gravity of the fluid

'$v_1$' is the flow velocity of the fluid at position 1; and

'$v_2$' is the flow velocity of the fluid at position 2.

From this follows that the flow pressure drop '$\Delta p_{1-2}$' of the fluid through said restriction is influenced by changes in the specific gravity of the fluid and/or changes in the flow velocity of the fluid through the restriction.

As mentioned in the above, there will normally be small variations and/or changes in the specific gravity values for the inflowing fluids in the course of a production period, especially in the specific gravity values for the inflowing liquids, in contradiction to the large fluctuations that may often occur in the viscosity values of the fluids during the same period. Consequently, the pressure drop '$\Delta p_{1-2}$' will change very little as a result of differences or changes in the specific gravity of the fluids, and consequently '$\Delta p_{1-2}$' is mainly influenced by changes in the flow-velocity of the fluids through said restriction. It is possible to change and thereby control this pressure drop through appropriately changing the flow velocity of the fluids through the restriction, and where the flow velocity of the fluids is changed by selecting a suitable cross section of flow for the restriction, or possibly distributing this cross section of flow between several smaller and close-lying restrictions of this type. Such rheological relations and evaluations are otherwise known to those skilled in the art, and decisions regarding concrete and appropriate dimensions such as the cross section of flow of a restriction, are therefore of a professional nature, and as such are not discussed further in this connection.

Moreover, this type of potential for influence and control is what this invention makes appropriate use of, and what is characteristic of the present invention when compared with prior art.

In practice, these rheological conditions are utilised through one or more such short flow restrictions being provided in association with a cavity formed between an

external housing and an internal pipe, the internal pipe constituting a length of the production tubing, and where said cavity is connected with the internal bore of the pipe, and consequently of the production tubing, via one or more through openings in the wall of the internal pipe, and where the cavity is formed to carry fluids, whereby inflowing fluids are passed through the flow restriction(s) and said opening(s) in the pipe wall, whereupon the fluids may flow downstream and on through the production tubing. This assembly of components in principle constitutes the flow arrangement according to this invention.

Such a flow arrangement is arranged in a position along the inflow portion of the production tubing in the well. In a reservoir, the arrangement is arranged between the surrounding reservoir zone and the internal bore of the production tube. In addition, it may be appropriate to arrange such a flow arrangement in one or more positions along the entire or parts of the inflow portion of the well. When using several such flow arrangements, each flow arrangement is arranged at a suitable distance from the neighbouring flow arrangement(s). In addition, each flow arrangement may be given a separate and adapted cross section of flow, through which inflowing fluids may flow and be throttled. If a flow arrangement comprises several such restrictions, said cross section of flow is distributed between all the restrictions in an expedient manner, e.g. equally. By so doing, each flow arrangement may also be designed to effect its own and adjusted flow pressure drop, and where this pressure drop is optionally distributed between several restrictions in an expedient manner, e.g. equally.

By arranging for each flow arrangement to have an adjusted pressure drop, the differential pressure that drives the reservoir fluids from the outside of the production tubing and up to, and through, the flow arrangement in question and then directly or indirectly into the internal bore of the production tube, will also be reduced in an appropriate manner. In a horizontal well, where said differential pressure normally increases strongly in the downstream direction of the inflow portion of the well, there will consequently be a corresponding and strongly increasing need to throttle the flow rate of the inflowing reservoir fluids in the downstream direction. As an example, this effect may be achieved through one or more upstream portions of the production tubing not being provided with such flow arrangements, thereby not throttling the inflowing fluids through such arrangements, allowing the fluids to flow directly in through openings or perforations in the production tubing, or the fluids may possibly first flow via one or more upstream sand screens or similar devices. On the other hand, downstream portions of the production tubing may be provided with a suitable number of such flow arrangements, each flow arrangement being arranged at a suitable position along the inflow portion of the horizontal well, the fluids from these portions of the well optionally also flowing via upstream sand screens or similar devices, and where each flow arrangement is arranged so as to effect a suitable pressure drop when the reservoir fluids are led up to and passed through the flow arrangement in question. Seen in relation to said upstream portions of the production tubing, said downstream portions of the production tubing are not, or to a significantly smaller extent, provided with ordinary openings or perforations through which the reservoir fluids can flow, and where this is done precisely to be able to lead the

reservoir fluids up to and through said flow arrangements, thereby to be able to control the behaviour of the fluid flow.

In addition, single or groups of flow arrangements in a well may be connected to different production zones in the reservoir(s) penetrated by the well, and where for production purposes, the different production zones are separated by means of pressure and flow isolating packings provided in the annulus between the production tubing and the surrounding reservoir rocks, or possibly in the annulus between the production tubing and the surrounding production liner, and also between the various production zones.

Prior to completing or re-completing a well, e.g. a horizontal well, more information is normally gathered regarding the production characteristics, fluids, pressure, temperature etc. of the reservoir rocks. Based on this information, together with the desired production rate and method(s) of production, reservoir heterogeneity, length of well inflow portion, calculated flow pressure drop through the production tubing etc., it is possible, both physically and timewise, to estimate a probable flow and pressure gradient, or a flow and pressure profile, for the inflowing fluids. On the basis of such information, it is then possible to estimate and determine the concrete need for such flow arrangements in the well in question, including among other things number, relative positioning and density of positioning, individual designs, including the individual degree of throttling, of the flow arrangements. Such decisions must often be made, and the individual adjustments carried out, within very short time limits. It should

therefore be possible in a simple, efficient and flexible manner to arrange each such flow arrangement so as to effect a specific fluid pressure drop adjusted to a specific production rate and the prevailing conditions at the intended and relative downhole position of each arrangement along the inflow portion of the well.

According to this invention, the desired fluid pressure drop may easily be provided by designing the outside housing of the flow arrangement as a production tubing enclosing, axially running and tubular housing with a circular cross section, e.g. an axially extending sleeve, and where the internal cavity of the housing therefore appears as a circular annulus between the housing and the production tubing. The production tubing may optionally be provided with several such flow arrangements, the number and mutual spacing of which correspond to said and intended downhole positions along the inflow portion of the well. Among other things, such a flow arrangement contains one or more openings, e.g. bores, in an associated anchoring object, where each opening holds a complementary shaped flow restriction in the form of a nozzle, an orifice or a sealing plug. This flow restriction should be formed as an insert, preferably a removable and replaceable insert, the insert preferably but not necessarily being formed with an outside circular cross section. When using a removable and replaceable insert in such an opening, this opening hereinafter being termed an insert opening, the insert opening may be e.g. a radial bore or perforation through the pipe wall of the production tubing, immediately inside the annulus of the flow arrangement, or the insert opening may be an axial bore or perforation e.g. in a circular steel ring or steel collar provided for, e.g. placed

in, said annulus. Thereby, one nozzle insert having one specific internal nozzle diameter may be replaced with another nozzle insert having another internal nozzle diameter. Alternatively, a nozzle insert may be replaced with a sealing plug insert or vice versa. Moreover, various known fastening devices and fastening methods exist for removably placing such an insert in an associated opening; for this purpose, use may be made of among other things threaded connections, ring fasteners such as Seeger circlip rings, fixing plates, retaining sleeves or attachment screws.

To allow the use of replaceable inserts, it is assumed that preferably all insert openings in such a flow arrangement, optionally all insert openings in the flow arrangements of a well, have been constructed with the same shape and size, e.g. bores having the same diameter, and that at the same time, all insert openings are provided with inserts given a complementary external shape and size, e.g. nozzle inserts with the same external diameter, but where the nozzle inserts may have an individually adapted internal nozzle diameter, optionally with one or more insert openings fitted with sealing plug inserts. Furthermore, a flow arrangement in which the nozzle inserts are arranged in through openings in the pipe wall of the production tubing may be equipped with one or more pairs of nozzles, where two nozzle inserts in a pair of nozzles are placed diametrically opposite each other in said pipe wall, and where the nozzle inserts of such a pair of nozzles are arranged upon fluid flow to lead fluid jets issuing downstream towards each other, so that the jets meet in the internal bore of the production tubing, and that the issuing fluid jets impinge on the internal surface of the pipe wall with a reduced compressive force, or possibly do

not impinge on the pipe wall at all, so as to avoid subjecting the pipe wall to any appreciable erosion.

Moreover, the insert openings of such a flow arrangement should be easily accessible, so as to allow easy placement or possibly replacement of nozzle inserts or sealing plug inserts in the insert openings. At the same time, the nozzles/sealing plugs must be allowed to have the intended effect in the flow arrangement when this is arranged in its intended position in the inflow portion of the well. According to this invention, this accessibility is achieved by arranging the enclosing housing or sleeve of said annulus in such a manner as to create temporary access to said insert openings, e.g. bores, and their associated inserts. As an example, this may be done by providing suitable openings, e.g. bores, in the enclosing housing or sleeve, which openings when required may easily be uncovered or covered, e.g. by means of a removable covering plate or covering sleeve that may be placed over the openings of the house/sleeve. These openings must be placed immediately outside and across from the individual insert openings of the flow arrangements, so as to create access routes leading to these. Alternatively, the enclosing housing or sleeve may be removable arranged relative to the production tubing, so as to allow the housing/sleeve to be removed temporarily when one wants to place or replace inserts in the insert openings of the flow arrangement. This makes it possible, prior to running said production tubing into the well, and on the basis of above well and reservoir information, quickly to provide all flow arrangements in the production tubing with a suitable number of nozzles having an adapted, internal nozzle diameter, and thereby an appropriate flow pressure drop

across the individual nozzle, and any sealing plugs. Such sealing plugs are preferably used to seal insert openings through which no fluid flow is wanted. This is connected with the fact that prior to running in the production tubing, and before said well and reservoir information is available, it may be difficult to determine the exact number, relative positioning and individual design of the flow arrangements of the production tubing. It may therefore be expedient and time saving to provide a certain number of individual lengths of production tubing with flow arrangements of a standard design and with a standard number of empty insert openings. With the subsequent access to further well and reservoir information, one may then easily and quickly fit each of the empty insert openings with an adapted nozzle insert or a sealing plug.

The following part of the description will, with reference to the attached drawings, show two non-limiting examples of embodiments of a flow arrangement according to the invention, and where both of these flow arrangements can be used in association with the production tubing of a well, and in a manner such as described in the above. One specific reference number refers to the same detail in all drawings showing this detail, and where:

Figure 1 shows a partial axial section through a length of production tubing, and where this length is equipped with a flow arrangement according to the invention, the flow arrangement comprising among other things radial insert bores with associated nozzle inserts in the wall of the length of production tubing, and where this length is also provided with an upstream sand screen, and where the figure shows the

radial lines of section V-V and VI-VI through the length of production tubing;

Figure 2 is an enlarged circular cutout of details of the flow arrangement shown in figure 1, and where the relevant circular cutout is also shown in figure 1, and where the figure also shows the line of section V-V;

Figure 3 shows a partial axial section through a length of production tubing similar to that of figure 1, and where the length is equipped with another flow arrangement according to the invention, this flow arrangement comprising among other things axial insert bores with associated nozzle inserts in a collar section of a tubular housing enclosing the length of production tubing, which housing has a circular cross section, and where this length of tubing is equipped with an upstream sand screen, and where the figure, like figure 1, also shows the lines of section V-V and VI-VI;

Figure 4 is an enlarged circular cutout of details of the flow arrangement shown in figure 3, and where the relevant circular cutout is also shown in figure 3, and where the figure also shows the line of section V-V;

Figure 5 shows a partial radial section along the line of section V-V shown in figure 1 and figure 3, and where the partial section shows a connecting sleeve between the flow arrangement and said sand screen, the circumference of the connecting sleeve being provided with axial semicircular flow orifices, and where the figure also shows an axial line of section I-I through the length of tubing; and where

Figure 6 shows a partial radial section along the line of section VI-VI shown in figure 1 and figure 3, and where the partial section shows details of said sand screen, and where this figure shows the axial line of section I-I through the length of tubing.

For a first flow arrangement 10 according to the invention, reference is made to figure 1 and figure 2, and for a second flow arrangement 12, reference is made to figure 3 and figure 4, while figure 5 and figure 6 illustrate structural features common to both embodiments.

Common to both embodiments is also the fact that they are provided on a length of tubing 14 connected to other, possibly equivalent or similar, lengths of tubing not shown in the figure, which together make up the production tubing of a well. The length of tubing 14 consists of a base pipe with a pipe wall 16, each end of which is threaded and may be coupled to other lengths of tubing 14 via a threaded pipe coupling 18. For these examples of embodiments, the base pipe is equipped with an upstream sand screen 20. At one end portion, the sand screen 20 is connected to the pipe wall 16 of the base pipe by means of an inner end socket 22, which in this embodiment is fitted with an internal packing ring 23, as well as an enclosing and outer end socket 24. At the other end portion, by the flow arrangement 10 or 12, the sand screen 20 abuts a connecting sleeve 26, and where both the sand screen 20 and the connecting sleeve 26 are held against each other and against the pipe wall 16 by an outer end socket 28. With reference to figure 6, the sand screen 20 is equipped with several spacer strips 30 fixed to the outer periphery of the pipe wall 16 at a mutually equidistant

angular distance and running in the axial direction of the base pipe. On the outside and in the periphery of the spacer strips 30 are wound continuous, closely spaced wire windings 32, where a small slot opening appears between each wire winding 32, through which the reservoir fluids may flow from the surrounding reservoir rocks. Thus several axial flow channels 34 located around the circumference of the base pipe exist between successive and adjacent spacer strips 30, and also between the wire windings 32 and the pipe wall 16, through which channels 34 said fluids may flow up to and through the connecting sleeve 26. The connecting sleeve 26, cf. figure 5, is also formed with axial but semicircular flow channels 36 distributed equidistantly along the circumference of the connecting sleeve 26, through which channels 36 the fluids may flow further into one of the flow arrangements 10 or 12. It should in addition be pointed out that each individual axial flow channel 34 and 36 is formed with a relatively large cross section of flow, thus minimising the flow friction and associated fluid pressure loss upon fluid flow through channels 34 and 36, relative to the fluid pressure loss introduced to the fluids upon flow through downstream and short flow restrictions in the flow arrangement 10 or 12. Referring to the first embodiment and to figure 1 and figure 2, the fluids then flow into an annulus 38 in the flow arrangement 10. In this embodiment, the annulus 38 is constituted by the cavity that appears between the wall 16 of the base pipe and an enclosing and tubular housing 40 with a circular cross section, and where the upstream end portion of the housing 40 encloses the connecting sleeve 26, while the downstream end portion of the housing 40 encloses the pipe wall 16, the housing 40 at this downstream end portion, and in this embodiment, being equipped with an internal packing ring 41. In addition, a

section of the pipe wall 16 in direct contact with the annulus 38 is equipped with several through-going, threaded insert bores 42 of the same bore diameter, wherein a corresponding number of male threaded and through-going open nozzle inserts 44 are removably arranged. The nozzle inserts 44 may have one specific internal nozzle diameter, or they may have different internal nozzle diameters. All fluids flowing in through the sand screen 20 will be led up to and through the nozzle inserts 44, wherein a pressure drop is introduced to the fluids, and where the fluids then flow onwards downstream in the internal bore 46 of the base pipe. If fluid flow is unwanted through one or more insert bores 42, the insert bore(s) 42 in question may be provided with a threaded sealing plug insert (not shown). In order to allow placement or replacement of nozzle inserts 44 and/or sealing plug inserts in said insert bores 42, the housing 40 has been provided with through access bores 48, the number and positioning of which correspond to the internally positioned insert bores 42, and where nozzle inserts 44 and/or sealing plug inserts may be inserted or removed through the bores 48 by means of a suitable tool. The access bores 48 in the housing 40 are then sealed against the outside environment by means of a covering sleeve 50 arranged to be removable and preferably pressure tight on the outside of the tubular housing 40, by means of e.g. a threaded connection 51, whereupon the length of tubing 14 may be coupled with other pipes to form a continuous production tubing in a well.

Reference is now made to the second embodiment and to figure 3 and figure 4, and also to the flow arrangement 12 located downstream of said connecting sleeve 26. From the connecting sleeve 26, the reservoir fluids flow downstream and onwards

into a first annulus 52 in the flow arrangement 12. The annulus 52 is constituted by the cavity that appears between the pipe wall 16 of the base pipe and an enclosing and tubular housing 54 with a circular cross section, the annulus 52 being an integral part of the housing 54, and where the upstream end portion of the housing 54 encloses the connecting sleeve 26, while the downstream end portion of the housing 54 is formed with a substantial axial material thickness in the form of an annular collar section 56 enclosing the pipe wall 16, the collar section 56 in this embodiment being equipped with an internal packing ring 58. Furthermore, the circumference of the collar section 56 is provided with several axial through-going and threaded insert bores 60 of the same bore diameter, wherein is removably arranged a corresponding number of threaded and through-going open nozzle insert 62. Like in flow arrangement 10, nozzle inserts 62 with different internal nozzle diameters, or possibly a threaded sealing plug insert (not shown), may be placed in the insert bores 60. In addition, the collar section 56 internally has extension bores 64 connecting the insert bores 60 with the annulus 52. Moreover, the collar section 56 is, immediately outside of the insert bores 60, formed with an outer peripheral section 66 that is countersunk relative to the remaining part of the peripheral surface of the collar section 56. An upstream end portion of an annular housing 68 is arranged around said peripheral section 66 in a manner so as to be removable and preferably pressure tight, while a downstream end portion of the annular housing 68 encloses the pipe wall 16, the annular housing 68 in this downstream end portion and in this embodiment being equipped with an internal packing ring 70.

A second annulus 72 of the flow arrangement 12 thereby emerges between the pipe wall 16 and the annular housing 68. Reservoir fluids flowing through and being throttled in the upstream nozzle inserts 62 flow on into the annulus 72, through several axial slit openings 74 in the pipe wall 16, in order then to flow downstream and onwards in the internal bore 46 of the base pipe. The annular housing 68 may be detached and temporarily removed from the peripheral section 66 by means of e.g. a threaded connection 76. Thus access routes are created up to the insert bores 60, so as to allow the insertion or removal of nozzle inserts 62 and/or sealing plug inserts.

# Claims

1. A flow arrangement (10, 12) for use in a well of the type that penetrates one or more underground reservoirs, the well being equipped with a drain line/production tubing made up of several connected lengths of tubing (14), and where the arrangement (10, 12) is designed to throttle the pressure of reservoir fluids that, in an inflow portion of the drain line/production tubing in the well, flow in radially from said reservoir(s) through at least one flow arrangement (10, 12) and into the drain line/production tubing, and where the arrangement (10, 12) is designed to effect a relatively stable and predictable fluid pressure drop at any stable fluid flow rate in the course of the production period of the well, this fluid pressure drop being adjusted according to the prevailing pressure conditions and flow rates at the relevant position of the arrangement (10, 12) along the inflow portion of the production tubing, and where the arrangement (10, 12) is designed so that said fluid pressure drop is mainly influenced by the specific gravity and flow velocity of the inflowing liquids, and that the fluid pressure drop exhibits the smallest possible degree of susceptibility to influence by differences in the viscosity and/or any changes in the viscosity of said fluids during the production period, characterised in that the flow arrangement (10, 12) is constituted by a cavity formed between an outside housing and an inside base pipe of a length of tubing (14), and where said cavity is connected to the internal bore (46) of the base pipe via one or more through openings in the pipe wall (16) of

the base pipe, and where one or more short flow restrictions are arranged in separate through openings in an associated anchoring object provided for said cavity, and where the cavity is formed to carry fluids, whereby inflowing fluids are led through the flow restriction(s) and said opening(s) in the pipe wall (16), whereupon the fluids may flow downstream and onwards through the drain line/production tubing of the well.

2. A flow arrangement (10, 12) according to Claim 1, c h a r a c t e r i s e d i n that the short flow restriction is a nozzle.

3. A flow arrangement (10, 12) according to Claim 1, c h a r a c t e r i s e d i n that the short flow restriction is an orifice in the form of a slit or a hole.

4. A flow arrangement (10, 12) according to Claim 1, c h a r a c t e r i s e d i n that the short flow restriction is a sealing plug.

5. A flow arrangement (10, 12) according to one or more of claims 1-4, c h a r a c t e r i s e d i n that the flow restriction is formed as a removable and replaceable insert.

6. A flow arrangement (10, 12) according to Claim 5, c h a r a c t e r i s e d i n that an arrangement (10, 12) comprising several removable and replaceable

inserts is equipped with inserts of the same external size and shape.

7. A flow arrangement (10, 12) according to Claim 5 or 6, c h a r a c t e r i s e d i n that the removable and replaceable insert(s) is/are externally circular.

8. A flow arrangement (10, 12) according to Claim 1, c h a r a c t e r i s e d i n that the anchoring object is the pipe wall (16) of the base pipe, and that each flow restriction is thereby arranged in a through opening in the pipe wall (16).

9. A flow arrangement (10, 12) according to Claim 1, c h a r a c t e r i s e d i n that the anchoring object is an annular collar section (56) of the outside housing, and that the collar section (56) is arranged in the annulus between the outside housing and the pipe wall (16), and that each flow restriction is thereby arranged in a through opening in the collar section (56).

10. A flow arrangement (10, 12) according to Claim 1, 8 or 9, c h a r a c t e r i s e d i n that an anchoring object provided with several through openings is formed with openings of the same size and shape.

11. A flow arrangement (10, 12) according to Claim 1, 8, 9 or 10, c h a r a c t e r i s e d i n that each through opening in the anchoring object is an insert bore (42, 60).

12. A flow arrangement (10, 12) according to one or more of the preceding claims, c h a r a c t e r i s e d i n that each flow restriction arranged in an associated through opening in the anchoring object has an external size and shape that is complementary to the internal size and shape of the associated opening.

13. A flow arrangement (10, 12) according to one or more of the preceding claims, c h a r a c t e r i s e d i n that the associated flow restriction(s) is/are designed to have a, relative to the prevailing conditions, total and adjusted cross section of flow that upon fluid flow causes said fluid pressure drop through the arrangement (10, 12).

14. A flow arrangement (10, 12) according to Claim 13, c h a r a c t e r i s e d i n that the total cross section of flow in an arrangement (10, 12) consisting of several such flow restrictions, is equally or unequally divided between two or more flow restrictions.

15. A flow arrangement (10, 12) according to claims 8 and 11, c h a r a c t e r i s e d i n that a tubular housing (40) that encloses the arrangement (10, 12) is designed with one or more access bores (48), the bores (48) being disposed immediately outside and across from the insert bore(s) (42) of the arrangement (10, 12), which provides access to the insert bore(s) (42).

16. A flow arrangement (10, 12) according to Claim 15, c h a r a c t e r i s e d i n that the access bore(s)

(48) of the housing (40) may be uncovered or covered by use of a removable covering sleeve (50).

17. A flow arrangement (10, 12) according to claims 9 and 11, c h a r a c t e r i s e d i n that an annular housing (68) encloses the collar section (56) in a removable manner, enabling the annular housing (68) to be detached and temporarily removed from the collar section (56), which provides access to the insert bore(s) (60) of the collar section (56).

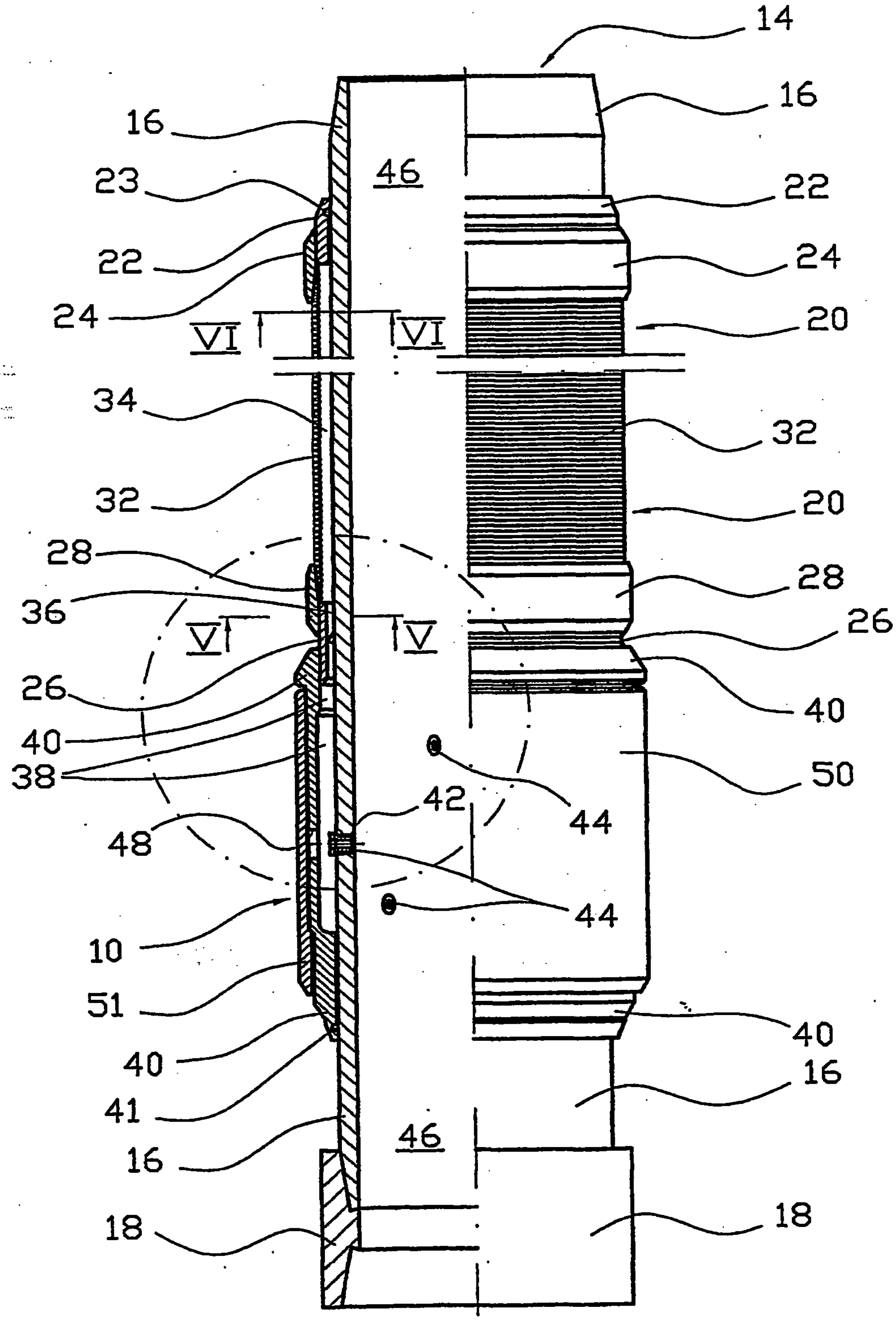
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Fig. 1

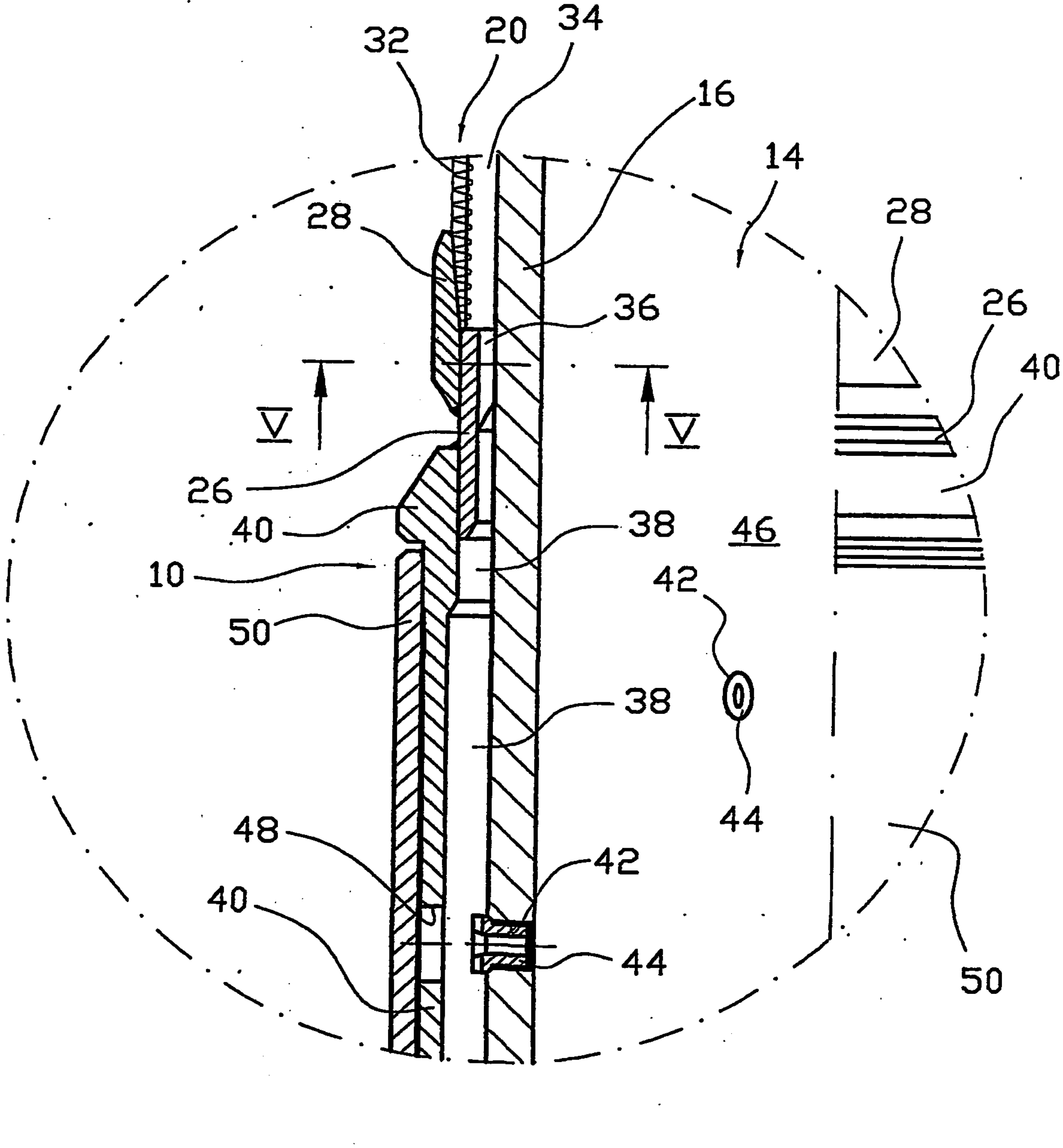
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Fig. 2

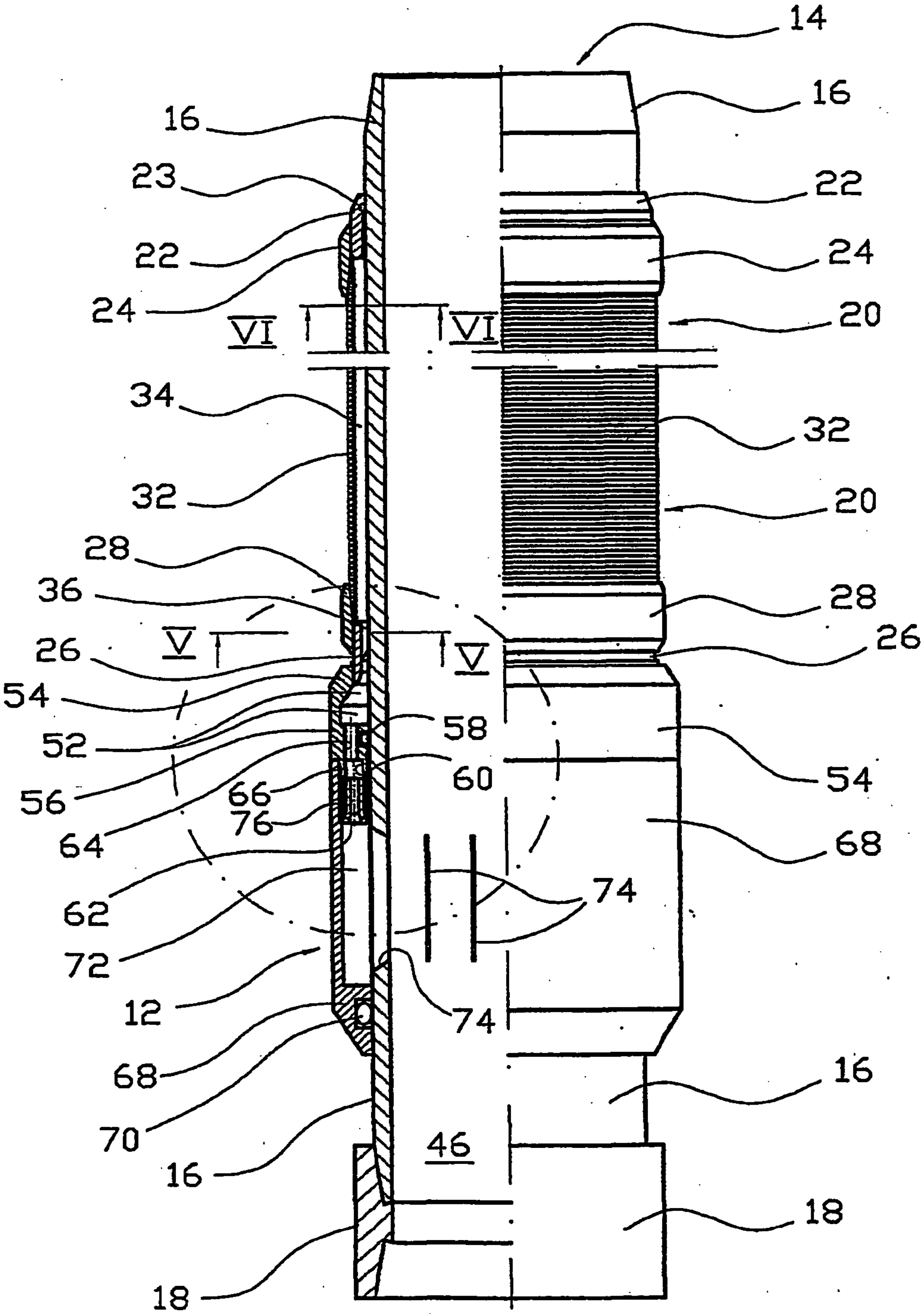
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Fig. 3

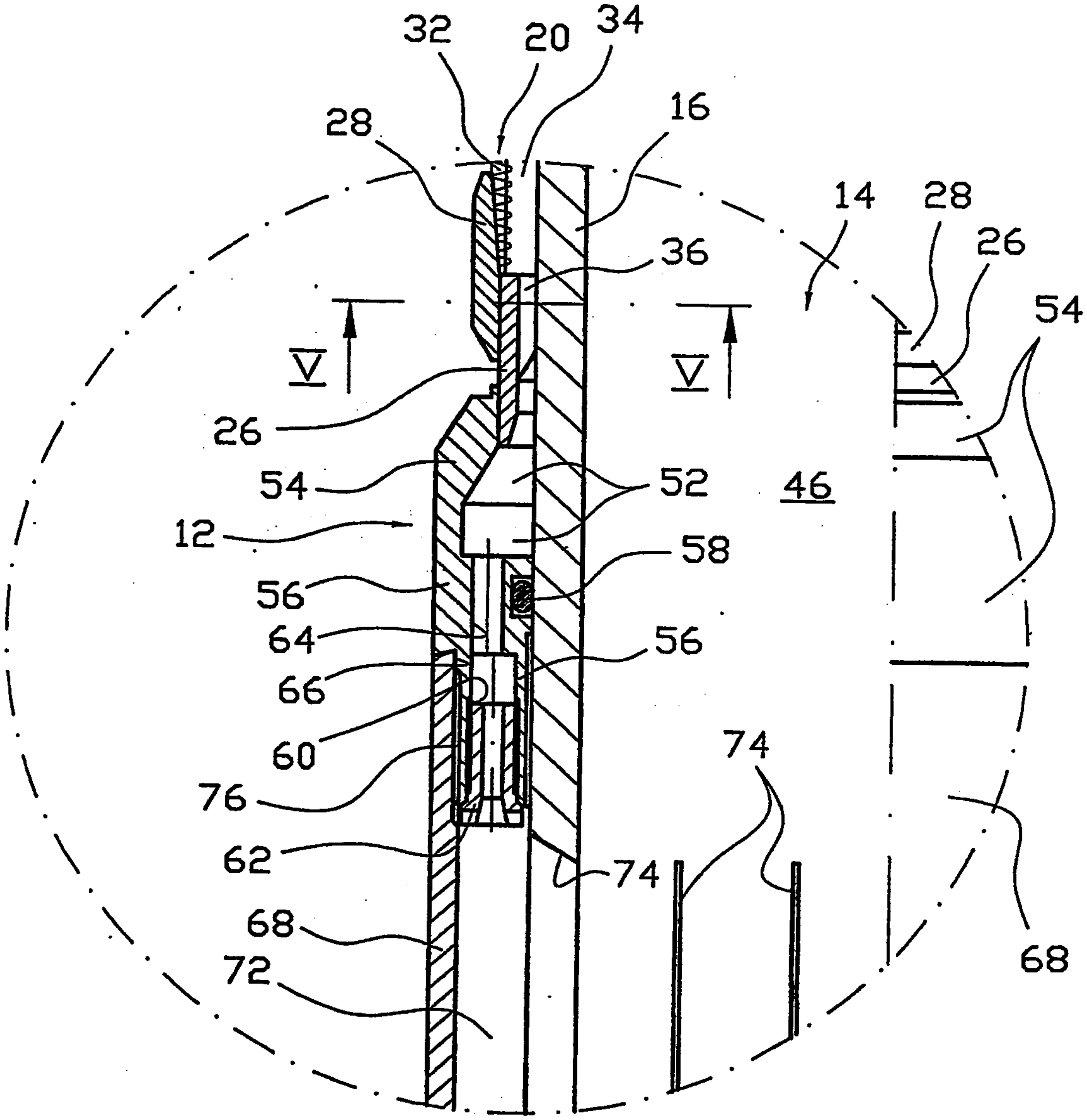
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Fig. 4

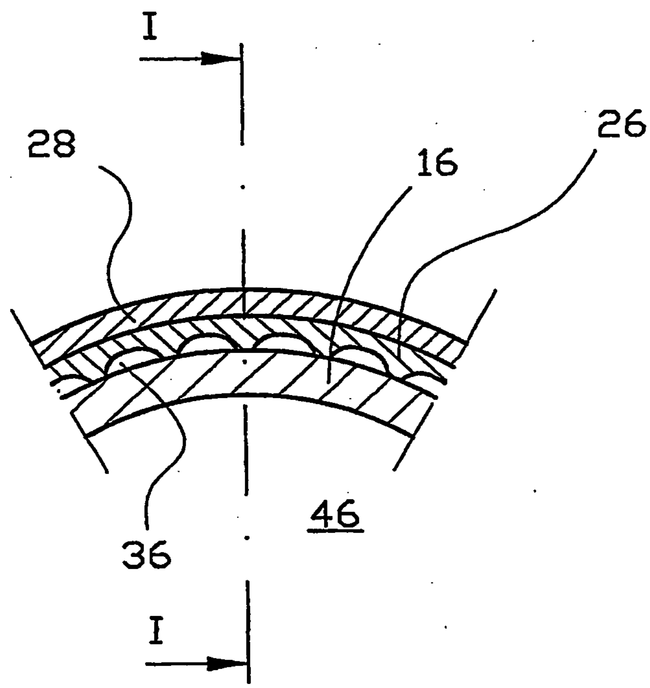


Fig. 5

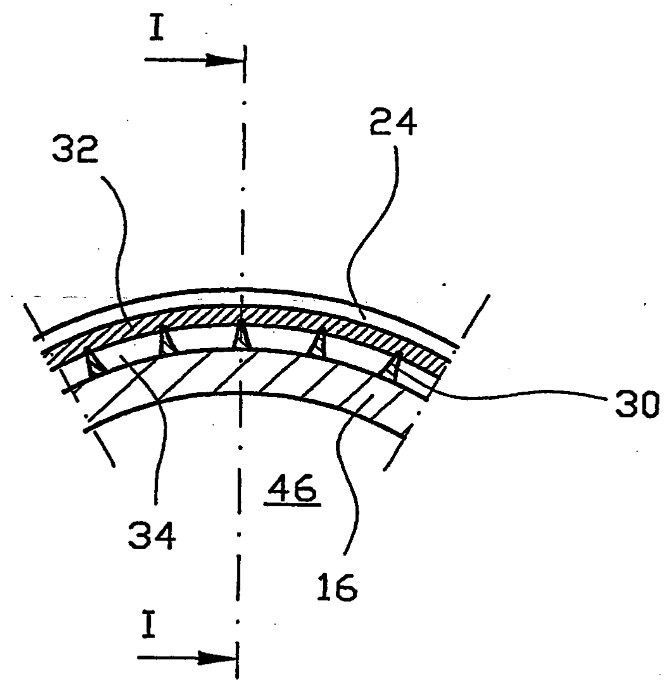


Fig. 6

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 02/00105

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC7: E21B 43/12
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC7: E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 25 June 2002 | 28 -06- 2002 |
| Name and mailing address of the ISA/<br>Swedish Patent Office<br>Box 5055, S-102 42 STOCKHOLM<br>Facsimile No. +46 8 666 02 86 | Authorized officer<br><br>Christer Bäcknert / MRo<br>Telephone No. +46 8 782 25 00 |

# INTERNATIONAL SEARCH REPORT

| International application No. |
|---|
| PCT/NO 02/00105 |

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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Information on patent family members

01/05/02

International application No.
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